Express Mail Label #EV 324573182 US

Method and Apparatus for Managing the Temperature of Thermal Components

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable.

BACKGROUND OF THE INVENTION

Field of the Invention

[0003] The present invention relates generally to temperature management systems. More particularly, the present invention relates to systems for managing the temperature of discrete thermal components.

Description of the Related Art

[0004] To drill a well, a drill bit bores thousands of feet into the crust of the earth. The drill bit extends downward from a drilling platform on a string of pipe, commonly referred to as a "drill string." The drill string may be jointed pipe or coiled tubing. At the lower, or distal, end of the drill string is a bottom hole assembly (BHA), which includes, among other components, the drill bit.

[0005] In order to obtain measurements and information from the downhole environment while drilling, the BHA includes electronic instrumentation. Various tools on the drill string, such as logging-while-drilling (LWD) tools and measurement-while-drilling (MWD) tools incorporate the instrumentation. Such tools on the drill string contain various electronic

components incorporated as part of the BHA. These electronic components generally consist of computer chips, circuit boards, processors, data storage, power converters, and the like.

[0006] Downhole tools must be able to operate near the surface of the earth as well as many thousands of feet below the surface. Environmental temperatures tend to increase with depth during the drilling of the well. As the depth increases, the tools are subjected to a severe operating environment. For instance, downhole temperatures are generally high and may even exceed 200°C. In addition, pressures may exceed 20,000 psi. In addition to the high temperature and pressure, there is also vibration and shock stress associated with operating in the downhole environment, particularly during drilling operations.

[0007] The electronic components in the downhole tools also internally generate heat. For example, a typical wireline tool may dissipate over 100 watts of power, and a typical downhole tool on a drill string may dissipate over 10 watts of power. Although there is electrical power dissipated by a drill string tool, the heat from the drilling environment itself still makes internal heat dissipation a problem. The internally dissipated heat must be removed from the electronic components or thermal failure will occur.

[0008] While performing drilling operations, the tools on the drill string typically remain in the downhole environment for periods of several weeks. In other downhole applications, drill string electronics may remain in the downhole for as short as several hours to as long as one year. For example, to obtain downhole measurements, tools are lowered into the well on a wireline or a cable. These tools are commonly referred to as "wireline tools." However, unlike in drilling applications, wireline tools generally remain in the downhole environment for less than twenty-four hours.

[0009] A problem with downhole tools is that when downhole temperatures exceed the temperature of the electronic components, the heat cannot naturally dissipate into the environment. The heat will accumulate internally within the electronic components unless there are provisions to remove the heat. Thus, two general heat sources must be accounted for in downhole tools, the surrounding downhole environment and the heat dissipated by the tool components, *e.g.*, electronics components.

[0010] While the temperatures of the downhole environment may exceed 200°C, the electronic components are typically rated to operate at no more than 125°C. Thus, due to the extended time downhole, heat transfer from the downhole environment and the heat dissipated by the components will result in thermal failure of those components. Generally, thermally induced failure has two modes. First, the thermal stress on the components degrades their useful lifetime. Second, at some temperature, the electronics fail and the components stop operating.

[0011] Thermal failure is very expensive. The expense is not only due to the replacement costs of the failed electronic components, but also because electronic component failure interrupts downhole activities. Trips into the borehole also use costly rig time. An effective apparatus and method to cool electronic components in downhole tools would greatly reduce costs incurred during downhole operations associated with thermal failure.

[0012] A traditional method of cooling the electronics in a downhole tool involves modest environmental temperatures, such as may be found near the surface of the earth. Near the surface of the earth, the electronics operate at a temperature above the environmental temperature. In modest environments, the electronics are thermally connected to the tool housing. The thermal connection allows the heat to dissipate to the environment by the natural heat transfer of

conduction, convection, and/or radiation. Temperature gradient cooling will only work, however, if the temperature gradient between the electronics and the environment is large enough to adequately cool the electronics.

[0013] A traditional method for reducing thermal failure in harsh thermal environments, such as thousands of feet below the surface of the earth, is to place the electronics on a chassis in an insulated vacuum flask. The vacuum flask acts as a thermal barrier to retard heat transfer from the downhole environment to the electronics. However, thermal flasks are passive systems that only slow the harmful effects of thermal failure. Because of the extended periods downhole in both wireline and drill string operations, insulated flasks do not provide sufficient thermal management for the electronic components for extended periods. Specifically, the flask does not remove the heat generated internally by the electronic components. Further, a thermal mass, such as a eutectic material, can be included in the flask to absorb heat from the downhole environment as well as the heat generated internally by the electronics. However, both the thermal flask and the thermal mass are only used to thermally manage the temperature of the interior of the electronics compartment. Because the discrete components are internally generating heat, they will remain at a higher temperature than the general interior of the electronics compartment. Thus, thermal failure continues to be a problem.

[0014] Another cooling method for deep-well cooling uses an active cooling system to cool electronics in a downhole tool. In this method, water in one tank is in thermal contact with the electronics chassis of the downhole tool. The water absorbs heat from the downhole environment and the electronics and begins to vaporize at 100°C so long as the pressure of the tank is maintained at 1.01×10^5 Pa (14.7 psi). In order to maintain the pressure, the steam is

removed from the tank and compressed in a second tank. However, sufficient steam must be removed from the first tank in order to maintain the pressure at 1.01×10^5 Pa. Otherwise, the boiling point of the water will rise and thus raise the temperature of the electronics chassis in the first tank.

[0015] In practice, active steam cooling has significant problems. First, this method has very large compression requirements because the compressed steam in the second tank cools to the temperature of the downhole environment. The compressor must be able to compress the steam to a pressure greater than the saturation pressure of steam at the temperature of the downhole environment, which is 1.55×10^6 Pa (225 psi) at 200°C. Second, this method is also time limited based on the amount of water in the first tank because when all the water in the first tank vaporizes, the cooling system will not function. In addition, the method does not isolate the electronic components but instead attempts to cool the entire electronics region. While the temperature of the region may remain at 100°C, the temperature of the discrete electronic components will be higher because they are internally generating heat. Consequently, this system does not effectively maintain the temperature of the discrete electronic components in order to minimize the effects of thermal failure.

[0016] Another cooling method attempts to resolve the problem of the high compression requirements of the above-mentioned cooling system by use of a sorbent cooling system. This method again uses the evaporation of a liquid that is in thermal contact with the electronic components to maintain the temperature of the components. Instead of using a compressor to remove the vapor, this method uses desiccants in the second tank to absorb the vapor as it evaporates in the first tank. However, the desiccants must absorb sufficient vapor in order to

maintain a constant pressure in the first tank. Otherwise, the boiling point of the liquid will rise as the pressure in the lower tank rises.

[0017] Like the previous method, the sorbent cooling system also has significant problems. First, sorbent cooling only cools the entire electronics region, not the discrete electronic components. Thus, because of internal heat dissipation, the electronic components may remain at a higher temperature than the entire electronics region. Second, the desiccants must absorb sufficient vapor in order to maintain a constant temperature in the first tank. Otherwise, the liquid will evaporate at a higher temperature and thus the temperature in the first tank will increase. Further, the amount of water in the first tank limits the system. Once all the water evaporates, the system no longer functions.

[0018] Other methods also cool electronics apart from downhole applications. For example, micro-channel heat exchangers cool microprocessors and other microelectronic devices in surface-based applications. However, these systems operate in an environment where the ambient temperature is less than the device being cooled. In a downhole environment, the ambient temperature is higher than the electronic components being cooled. These methods will not function properly in a downhole environment because they cannot remove the heat from the coolant in an environment where the ambient temperature is higher than the heated coolant.

[0019] None of the known cooling methods effectively and efficiently controls the temperature of electronic components in downhole tools. An effective cooling system for electronic components in downhole tools is one that performs either one or both of the following: (1) isolates thermally sensitive components from the environment; and (2) removes heat from thermally sensitive components. Consequently, to effectively manage the temperature of discrete

thermal components in downhole tools, the present invention has been developed. Other objects and advantages of the invention will appear from the following description.

SUMMARY OF THE EMBODIMENTS

[0020] The temperature management system manages the temperature of discrete thermal components in cavities in downhole tools, such as those suspended on a drill string or a wireline. The temperature management system comprises a heat exchanger in thermal contact with the thermal component, or a chassis of thermal components. The temperature management system also comprises a heat sink comprising a phase change material. A thermal conduit system connects the heat exchanger and heat sink in thermal communication. The thermal conduit system transfers heat absorbed by the heat exchanger from the thermal component to the heat sink. The heat sink in turn absorbs the heat from the thermal conduit as it changes phase. The temperature management system is thus able to discretely manage the temperature of thermal components inside a cavity instead of managing the temperature of the cavity as a whole.

[0021] In another embodiment, the thermal conduit system comprises a closed loop, coolant fluid conduit system. A fluid transfer device circulates coolant fluid through the conduit system. As the coolant fluid circulates through the thermal conduit system, the coolant flows through the heat exchanger, absorbing heat from the heat exchanger and enabling the heat exchanger to absorb more heat from the thermal component. After exiting the heat exchanger, the heated coolant fluid flows to the heat sink where the heat sink absorbs heat from the coolant, thus enabling the coolant to absorb more heat from the heat exchanger. After exiting the heat sink, the coolant fluid again circulates through the temperature management system.

[0022] Alternatively, the temperature management system may comprise an open loop,

coolant fluid conduit system. Instead of re-circulating coolant fluid through the fluid conduit system, the temperature management system expels the coolant fluid after the coolant fluid flows through the heat exchanger and the heat sink.

[0023] In another embodiment, there are multiple thermal components, each thermal component or group of components requiring a separate heat exchanger. To accommodate the multiple heat exchangers, the thermal conduit system comprises thermal conduit branches that branch out to each heat exchanger and then join back together for flow to the heat sink. The multiple heat exchangers may be arranged in series, in parallel, or any combination of series and/or parallel. Alternatively, the temperature management system further comprises valves for controlling fluid flow through each thermal conduit branch if the conduit system is a coolant fluid conduit system. The valves can control the flow through the thermal conduit branches to isolate particular heat exchangers from the temperature management system when the cooling of that component or group of components is not necessary.

[0024] In another embodiment, the temperature management system comprises a thermal barrier to the downhole environment. The thermal barrier acts to hinder heat transfer from the downhole environment to the thermal components. Such a barrier may be an insulated vacuum "flask" or any other suitable barrier.

[0025] Thus, the embodiments comprise a combination of features and advantages that overcome the problems of prior art devices. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the embodiments, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] For a more detailed description of the embodiments, reference will now be made to the following accompanying drawings:

FIGURE 1 is a schematic view showing a temperature management system;

FIGURE 2 is a schematic view showing a second embodiment temperature management system;

FIGURE 3 is a schematic view showing the components of the second embodiment temperature management system;

FIGURE 4 is a schematic view showing a third embodiment temperature management system;

FIGURE 5 is a schematic view showing a fourth embodiment temperature management system;

FIGURE 6 is a schematic view showing a fifth embodiment temperature management system; and

FIGURE 7 is a schematic view showing a sixth embodiment temperature management system.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0027] The present invention relates to a thermal component temperature management system and includes embodiments of different forms. The drawings and the description below disclose specific embodiments of the present invention with the understanding that the embodiments are to be considered an exemplification of the principles of the invention, and are not intended to limit the invention to that illustrated and described. Further, it is to be fully recognized that the

different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce desired results.

[0028] FIGURE 1 shows a temperature management system 10 disposed in a downhole tool 14 such as on a drill string 16 for drilling a borehole 13 in a formation 17. The temperature management system 10 might also be used in a downhole wireline tool, a permanently installed downhole tool, or a temporary well testing tool. Downhole, the ambient temperature can be extremely thermally harsh, sometimes exceeding 200°C. However, the temperature management system 10 may also be used in other situations and applications where the surrounding environment ambient temperature is either greater than or less than that of the thermal components being cooled.

[0029] The temperature management system 10 discretely manages the temperature of a thermal component 12 mounted on a board 18 in the downhole tool 14. The thermal component 12 comprises, but is not limited to, heat-dissipating components, heat-generating components, and/or heat-sensitive components. An example of a thermal component 12 is a heat-generating computer chip that is heat-sensitive. The board 18 is in turn mounted on a chassis (not shown) and installed within a cavity 15 of the tool 14. The temperature management system 10 further comprises a heat exchanger 20 in thermal communication with the thermal component 12. The heat exchanger 20 is in direct thermal contact with the thermal component 12. However, the heat exchanger 20 may also be in indirect thermal contact with the thermal component 12. The heat exchanger 20 may be any appropriate type of heat exchanger such as a conduction heat exchanger that uses heat conduction to transfer the heat through solids. The heat exchanger 20 may also comprise multiple layers of different materials.

[0030] The temperature management system 10 also comprises a heat sink 22 comprising a phase change material. Phase change material is designed to take advantage of the heat absorbed during the phase change at certain temperature ranges. For example, the phase change material may be a eutectic material. Eutectic material is an alloy having a component composition designed to achieve a desired melting point for the material. The desired melting point takes advantage of latent heat of fusion to absorb energy. Latent heat is the energy absorbed by the material as it changes phase from solid into liquid. Thus, when the material changes its physical state, it absorbs energy without a change in the temperature of the material. Therefore, additional heat will only change the phase of the material, not its temperature. To take advantage of the latent heat of fusion, the eutectic material would have a melting point below the boiling point of water and below the desired maintenance temperature of the thermal component 12.

[0031] The heat sink 22 is stored in a jacket 24 capable of withstanding the extreme downhole temperatures and shock conditions. For example, the jacket 24 can be a stainless steel container. Because the heat sink 22 may undergo a phase change, the jacket 24 must also be capable of withstanding the contraction and/or expansion of the heat sink 22.

[0032] The heat exchanger 20 and heat sink 22 are in thermal communication via a thermal conduit system 26. The thermal conduit system 26 comprises a thermally conductive material for transferring heat from the heat exchanger 20 to the heat sink 22. The thermal conduit system 26 may connect to the heat exchanger 20 and the heat sink 22 by any suitable means such as welding joints or threaded connections.

[0033] The temperature gradient between thermal component 12 and the heat sink 22 is such that the heat sink 22 absorbs the heat from the thermal component 12 through the heat exchanger

20 and the thermal conduit system 26. The temperature management system 10 removes enough heat to maintain the thermal component 12 at or below its rated temperature, which is typically no more than 125°C. For example, the temperature management system 10 may maintain the component 12 at or below 100°C, or even at or below 80°C. The lower the temperature, the longer the life of the thermal component 12.

[0034] Thus, the temperature management system 10 does not absorb heat from the entire cavity 15 or even the entire electronics chassis, but only the thermal component 12 itself. When absorbing heat discretely from the thermal component 12, the temperature management system 10 may allow the general temperature of the cavity 15 to reach a higher temperature than prior art cooling systems. However, even though the temperature of the cavity 15 may be higher, the temperature of the thermal component 12 will be lower than prior art cooling system components. Absorbing heat discretely from the thermal component 12 thus extends the useful life of the thermal component 12 as compared to prior art cooling systems, despite the temperature of the cavity 15 being higher.

[0035] Because the temperature of the downhole environment may be greater than the temperature of the heat sink 22, the heat removed from the thermal conduit 26 is stored in the heat sink 22. Consequently, the amount of heat the heat sink 22 can absorb from the thermal component 12 limits the temperature management system 10. When the heat sink 22 reaches its heat storage capacity, the downhole tool 14 is brought up closer to the surface or removed from the well 13 and the heat stored in the heat sink 22 dissipates into the cooler environment.

[0036] FIGURES 2 and 3 show an alternative temperature management system 210. The temperature management system 210 also discretely cools a thermal component 212 using a heat

exchanger 220 to absorb heat from the thermal component 212. The heat exchanger 220 transfers the absorbed heat through a thermal conduit system 226 to a heat sink 222. The heat sink 222 also comprises a phase change material and is enclosed in a jacket 224.

[0037] Unlike the temperature management system 10, the heat exchanger 220 in the temperature management system 210 is a micro-capillary heat exchanger. The micro-capillary heat exchanger 220 is a micro-channel, cold plate heat exchanger with stacked plates 220a enclosed in a housing 220b shown in FIGURE 3. The housing 220b includes inlet port 220c and outlet port 220d. To reduce the pressure drop through the micro-capillary exchanger 220, the plates 220a of the exchanger 220 are stacked as shown in FIGURE 3. The number of stacked plates 220a may be varied to optimize pressure drop, heat transfer, and other characteristics. In addition, the plates 220a of the micro-capillary exchanger 220 may be of any suitable material, such as copper or silicon.

[0038] The temperature management system 210 also differs from the temperature management system 10 shown in FIGURE 1 in that the thermal conduit system 226 is a coolant fluid conduit system. The thermal conduit system 226 allows the passage of coolant fluid from the heat exchanger 220 to the heat sink 222. The thermal conduit system 226 also allows the coolant fluid to return to the heat exchanger 220 to form a closed-loop system.

[0039] Located in the thermal conduit system 226 is a fluid transfer device 228 for flowing the coolant fluid through the thermal conduit system 226. The fluid transfer device 228 may be any suitable device for flowing the coolant fluid. By way of non-limiting example, the fluid transfer device may be a pump, such as a mini-pump or a micro-pump. The fluid transfer device 228 may be located at any suitable location in the thermal conduit system 226. In addition, the

fluid transfer device 228 may also circulate the coolant fluid in either flow direction.

[0040] The coolant fluid flowing within the thermal conduit system 226 is a coolant fluid in thermal communication with the heat exchanger 220 and the heat sink 222. The coolant fluid may be water or any other suitable fluid. The temperature management system 210 is a single-phase temperature management system. Thus, the coolant is a liquid and does not undergo a phase change while it circulates through the temperature management system 210. Alternatively, the temperature management system 210 may be a two-phase system where the coolant fluid changes to a gas phase and then back to the fluid phase as it cycles through the temperature management system 210. The two-phase system coolant fluid absorbs heat as it changes from the liquid to the gas phase and releases heat as it changes from the gas to the liquid phase.

[0041] In operation, the coolant travels from the fluid transfer device 228 to the heat exchanger 220 where the coolant is in thermal communication with the heat exchanger 220. The coolant passes into the inlet port 220c of the heat exchanger 220 and flows through the stacked plates 220a. As the coolant flows through the heat exchanger 220, it absorbs heat from the heat exchanger 220, thus allowing the heat exchanger 220 to absorb more heat from the thermal component 212. Upon exiting the heat exchanger 220 through outlet port 220d, the heated coolant flows through the thermal conduit system 226 to the heat sink 222. The heat sink 222 absorbs heat from the coolant, returning the coolant to a lower temperature. The thermal conduit system 226 maintains the coolant fluid separate from the phase change material inside the heat sink 222. The path of the thermal conduit system 226 through the heat sink 222 may be straight or tortuous depending on the performance specifications of the temperature management system 210. After exiting the heat sink 222, the coolant flows to the fluid transfer device 228, where it

circulates through the temperature management system 210 again.

[0042] The temperature management system 210 removes enough heat to maintain the thermal component 212 at or below its rated temperature, which is typically no more than 125°C. For example, the temperature management system 210 may maintain the thermal component 212 at or below 100°C, or even at or below 80°C. The lower the temperature, the longer the life of the thermal component 212.

[0043] Thus, the temperature management system 210 does not absorb heat from the entire cavity 215 or even the entire electronics chassis, but only the thermal component 212 itself. When absorbing heat discretely from the thermal component 212, the temperature management system 210 may allow the general temperature of the cavity 215 to reach a higher temperature than prior art cooling systems. However, even though the temperature of the cavity 215 may be higher, the temperature of the discrete thermal component 212 will be lower than prior art cooling system components. Absorbing heat discretely from the component 212 thus extends the useful life of the thermal component 212 as compared to prior art cooling systems, despite the temperature of the cavity 215 being higher.

[0044] Because the temperature of the downhole environment may be greater than the temperature of the heat sink 222, the heat removed from the coolant is stored in the heat sink 222. Consequently, the amount of heat the heat sink 222 can absorb from the thermal component 212 limits the temperature management system 210. When the heat sink 222 reaches its heat storage capacity, the downhole tool 214 is brought up closer to the surface or removed from the well 213 and the heat stored in the heat sink 222 dissipates into the cooler environment.

[0045] FIGURE 4 shows an alternative temperature management system 410. The

temperature management system 410 also discretely absorbs heat from a thermal component 412 using a heat exchanger 420. The heat exchanger 420 in the temperature management system 410 is also a micro-capillary heat exchanger similar to the heat exchanger 220 shown in FIGURES 3 and 4. The heat exchanger 420 transfers the absorbed heat through a thermal conduit system 426 from a heat sink 422. The heat sink 422 comprises a phase change material and is enclosed in a jacket 424.

[0046] The temperature management system 410 also uses a fluid thermal conduit system 426. The thermal conduit system 426 allows the passage of the coolant fluid from the heat sink 422 to the heat exchanger 420. Unlike the thermal conduit system 226 shown in FIGURE 2 however, the thermal conduit system 426 is an open loop system as shown in FIGURE 4. Thus, the coolant fluid cycles through the temperature management system 410 only once and then is expelled from the temperature management system 410.

[0047] Located in the thermal conduit system 426 is a fluid transfer device 428 for flowing the coolant fluid through the thermal conduit system 426. The fluid transfer device may be located at any suitable location in the temperature management system 410. The fluid transfer device 428 may also be any suitable device for flowing the coolant fluid. By way of non-limiting example, the fluid transfer device may be a pump, such as a mini-pump or a micro-pump. The coolant fluid flowing within the thermal conduit system 426 is in thermal communication with the heat exchanger 420 and the heat sink 422. The coolant fluid may be water or any other suitable fluid.

[0048] The temperature management system 410 is a single-phase temperature management system. Thus, the coolant is a liquid and does not undergo a phase change while it circulates

through the temperature management system 410. Alternatively, the temperature management system 410 may be a two-phase system where the coolant fluid changes to a gas phase as it flows through the temperature management system 410. The two-phase system coolant fluid absorbs heat as it changes from the liquid to the gas phase.

[0049] As shown in FIGURE 4, the coolant fluid travels from the low temperature heat sink 422 to the heat exchanger 420 where the coolant is in thermal communication with the heat exchanger 420. The heat exchanger 420 is in turn in either direct or indirect thermal contact with the thermal component 412. As the coolant flows through the heat exchanger 420, it absorbs heat from the heat exchanger 420, allowing the heat exchanger 420 to absorb more heat from the thermal component 412. Upon exiting the heat exchanger 420, the heated coolant flows through the thermal conduit system 426 and is expelled from the temperature management system 410 as shown by direction arrow 432.

[0050] The temperature management system 410 removes enough heat to maintain the thermal component 412 at or below its rated temperature, which is typically no more than 125°C. For example, the temperature management system 410 may maintain the thermal component 412 at or below 100°C, or even at or below 80°C. The lower the temperature, the longer the life of the thermal component 412.

[0051] Thus, the temperature management system 410 does not absorb heat from the entire cavity 415 or even the entire electronics chassis, but only the thermal component 412 itself. When discretely absorbing heat from the thermal component 412, the temperature management system 410 may allow the general temperature of the cavity 415 to reach a higher temperature than prior art cooling systems. However, even though the temperature of the cavity 415 may be

higher, the temperature of the discrete thermal component 412 will be lower than prior art cooling system components. Discretely absorbing heat from the thermal component 412 thus extends the useful life of the thermal component 412 as compared to prior art cooling systems, despite the temperature of the cavity 415 being higher.

[0052] The amount of cooling fluid and the heat absorption capacity of the heat sink 422 limit the amount of heat the temperature management system 410 can absorb from the thermal component 412. When the cooling fluid is depleted, the downhole tool 414 is removed from the well 413 to be supplied with more coolant fluid.

[0053] FIGURE 5 shows an alternative temperature management system 510. The temperature management system 510 may be configured such that the coolant fluid flows through a heat exchanger 520 and then through the thermal conduit system 526 to the heat sink 522, similar to the temperature management system 210 shown in FIGURES 2 and 3. As the fluid transfer device 528 flows coolant through the heat sink 522, the heat sink 522 absorbs heat from the coolant fluid. The thermal conduit system 526 maintains the coolant fluid separate from the phase change material inside the heat sink 522. The path of the thermal conduit system 526 through the heat sink 522 may be straight or tortuous depending on the performance specifications of the temperature management system 510. Unlike the temperature management system 210 shown in FIGURE 2, the temperature management system 510 is an open loop system similar to temperature management system 410 shown in FIGURE 4. Thus, after exiting the heat sink 522, the coolant is expelled from the temperature management system 510.

[0054] Located in the thermal conduit system 526 is a fluid transfer device 528 for flowing the coolant fluid through the thermal conduit system 526. The fluid transfer device may be

located at any suitable location in the temperature management system 510. The fluid transfer device 528 may also be any suitable device for flowing the coolant fluid. By way of non-limiting example, the fluid transfer device may be a pump, such as a mini-pump or a micro-pump. The coolant fluid flowing within the thermal conduit system 526 is in thermal communication with the heat exchanger 520 and the heat sink 522. The coolant fluid may be water or any other suitable fluid.

[0055] The temperature management system 510 is a single-phase temperature management system. Thus, the coolant is a liquid and does not undergo a phase change while it circulates through the temperature management system 510. Alternatively, the temperature management system 510 may be a two-phase system where the coolant fluid changes to a gas phase as it flows through the temperature management system 510. The two-phase system coolant fluid absorbs heat as it changes from the liquid to the gas phase.

[0056] As shown in FIGURE 5, the coolant fluid travels through the heat exchanger 520. The heat exchanger 520 is in either direct or indirect thermal contact with the thermal component 512. As the coolant flows through the heat exchanger 520, it absorbs heat from the heat exchanger 520, allowing the heat exchanger 520 to absorb more heat from the thermal component 512. Upon exiting the heat exchanger 520, the heated coolant flows through the thermal conduit system 526 and then through the heat sink 522. After passing through the heat sink 522, the coolant is expelled from the temperature management system 510 as shown by direction arrow 532.

[0057] The temperature management system 510 removes enough heat to maintain the thermal component 512 at or below its rated temperature, which is typically no more than 125°C.

For example, the temperature management system 510 may maintain the thermal component 512 at or below 100°C, or even at or below 80°C. The lower the temperature, the longer the life of the thermal component 512.

[0058] Thus, the temperature management system 510 does not absorb heat from the entire cavity 515 or even the entire electronics chassis, but only the thermal component 512 itself. When discretely absorbing heat from the thermal component 512, the temperature management system 510 may allow the general temperature of the cavity 515 to reach a higher temperature than prior art cooling systems. However, even though the temperature of the cavity 515 may be higher, the temperature of the discrete thermal component 512 will be lower than prior art cooling system components. Discretely absorbing heat from the thermal component 512 thus extends the useful life of the thermal component 512 as compared to prior art cooling systems, despite the temperature of the cavity 515 being higher.

[0059] The amount of cooling fluid and the heat absorption capacity of the heat sink 522 limit the amount of heat the temperature management system 510 can absorb from the thermal component 512. When the cooling fluid is depleted, the downhole tool 514 is removed from the well 513 to be supplied with more coolant fluid.

[0060] FIGURE 6 shows another alternative temperature management system 610. The temperature management system 610 can be configured for any of the preceding temperature management systems 10, 210, 410, 510. However, as an example only, the temperature management system 610 will be discussed with reference to the temperature management system 210 shown in FIGURE 2. Unlike the previous temperature management systems, the temperature management system 610 may be used to remove heat from multiple thermal

components 612 with multiple heat exchangers 620. A single heat exchanger 620 may also remove heat from a group of thermal components 612. To accommodate the multiple heat exchangers 620, the thermal conduit system 626 additionally comprises thermal conduit branches 631 directing coolant to each heat exchanger 620. FIGURE 6 shows the heat exchangers 620 connected in parallel. However, the heat exchangers 620 may also be in series, or any combination of series and/or parallel. After the coolant exits each heat exchanger 620, the thermal conduit branches 631 rejoin to form a single thermal conduit flowing to the heat sink 622. Alternatively, there are valves 630 for controlling fluid flow to each heat exchanger 620. The valves 630 can control flow of the coolant fluid to isolate particular heat exchangers 620 from the thermal conduit system 626 when the cooling of that component or group of components 612 is not necessary.

[0061] FIGURE 7 shows another alternative temperature management system 710. The temperature management system 710 can be configured for any of the preceding temperature management systems 10, 210, 410, 510, 610. However, as an example only, the temperature management system 710 will be discussed with reference to the temperature management system 210 shown in FIGURE 2. In addition to the components of the temperature management system 210 shown in FIGURE 2, the temperature management 710 further comprises a thermal barrier 740 enclosing the entire temperature management system 710 and chassis. The thermal barrier 740 thus separates the temperature management system 710 from the downhole environment. Although FIGURE 7 shows the thermal barrier 740 enclosing the entire temperature management system 710, the thermal barrier 740 may also enclose only a portion of the temperature management system 710. The thermal barrier 740 hinders heat transfer from the outside

environment to the temperature management system 710 and the thermal component 712. By way of non-limiting example, the barrier 740 may be an insulated vacuum "flask", a vacuum "flask" filled with an insulating solid, a material-filled chamber, a gas-filled chamber, a fluid-filled chamber, or any other suitable barrier. In addition, the space 742 between the thermal barrier 740 and the tool 714 may be evacuated. Creating a vacuum aids in hindering heat transfer to the temperature management system 710 and the thermal component 712. The temperature management system 710 may also cool multiple thermal components, as in the temperature management system 610 shown in FIGURE 6.

[0062] While specific embodiments have been shown and described, modifications can be made by one skilled in the art without departing from the spirit or teaching of this invention. The embodiments as described are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited to the embodiments described, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.